AEROSPACE REPORT NO.
TR-2007(1210)-1

Pico Satellite Solar Cell Testbed (PSSC Testbed)

25 September 2007

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System Planning and Engineering

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. FA8802-04-C-0001 with the Space and Missile Systems Center, 483 N. Aviation Blvd., El Segundo, CA 90245. It was reviewed and approved for The Aerospace Corporation by B. Jaduszliwer, Principal Director, Electronics and Photonics Laboratory; and G. F. Hawkins, Principal Director, Space Materials Laboratory; P. B. Grant, Principal Director, Electronics Engineering Subdivision; and M. A. Hopkins, Principal Director, Space and Directed Energy Technology. Henry Yoo was the project officer for the program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

H. Yoo

Henry Yoo
AFRL/VSSV

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (*DD-MM-YYYY*)	2. REPORT TYPE	3. DATES COVERED *(From - To)*
25-09-2007		

4. TITLE AND SUBTITLE

Pico Satellite Solar Cell Testbed (PSSC Testbed)

5a. CONTRACT NUMBER
FA8802-04-C-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

E. J. Simburger, S. Liu, J. S. Halpine, D. A. Hinkley,
D. L. Rumsey, J. E. Granata, and H. Yoo

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The Aerospace Corporation
Laboratory Operations
El Segundo, CA 90245-4691

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-2007(1210)-1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Space and Missile Systems Center
Air Force Space Command
483 N. Aviation Blvd.
El Segundo, CA 90245

10. SPONSOR/MONITOR'S ACRONYM(S)
SMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The PSSC Testbed flight experiment is designed to obtain space environment degradation data for advanced solar cells. The purpose of this particular experiment is to develop and operationally test the picosatellite and associated ground station.

This picosat could be the starting point for the development of a responsive space vehicle that would provide the capability of obtaining actual space environment exposure of new solar cell technology in a time frame that is in sync with the new-generation solar cell's introduction cycle.

Presently, there are two missions to be flown. The first mission has been manifested to fly on a Shuttle flight in mid 2008. The second mission will be a secondary payload on an EELV launch of a Geo payload. The PSSC Testbed will be inserted into a Geo Transfer orbit. This orbit will fly through the Van Allen Radiation Belts, resulting in an accelerated deposition of radiation when compared to LEO or GEO orbits. The equivalent of 15 years of radiation exposure that would be accumulated in a GEO orbit will be deposited on the solar cells in 300 days.

15. SUBJECT TERMS

Solar array, Solar cell, Space flight testing, Space environment effects

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ed Simburger
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		27	19b. TELEPHONE NUMBER *(include area code)* (310)336-7126

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Pico Satellite Solar Cell Testbed (PSSC Testbed)

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The Aerospace Corporation

Henry Yoo, AFRL/VSSV

Introduction & Background

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- The objective of PSSC is to improve reliability and increase confidence in newly introduced solar cell and related technologies
  - Testing solar cells "as you fly"
  - Obtaining solar cell degradation data in "relevant" space environment
- PSSC can be utilize for
  - Validate new technologies for space applications
  - Identify potential problems at cell/CICS level for new technologies

Introduction & Background

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- PSSC Testbed Designed to Measure Degradation of Advanced Technology Solar Cells in Actual Space Environment
  - Operational Missions to Fly in GEO Transfer orbit
  - Accelerated Radiation Exposure 300 Day Mission accumulates 15 Years Equivalent Radiation
- Develop Pico Satellite Bus Capable of Hosting Space Flight Experiments

PSSC Testbed Experiment Focus

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- Flight Experiment to Obtain Combined Space Environment Effects on CIC
  - Accelerated Radiation Effects
  - Thermal Cycling
  - Ultra Violet
  - Visible Light
  - Micrometeoroids
- Degradation Determined by Periodic Measurement of Current-Voltage Characteristic of the Solar Cells

Possible Experiments

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- Experiments can be Designed to Investigate Environmental Impacts on Various CIC Components
  - Solar Cell
  - Adhesives
  - Cover Glass
  - Cover Glass Coatings
  - Interconnects

Acceleration Factor for Radiation Total Dose GEO/GTO Orbits

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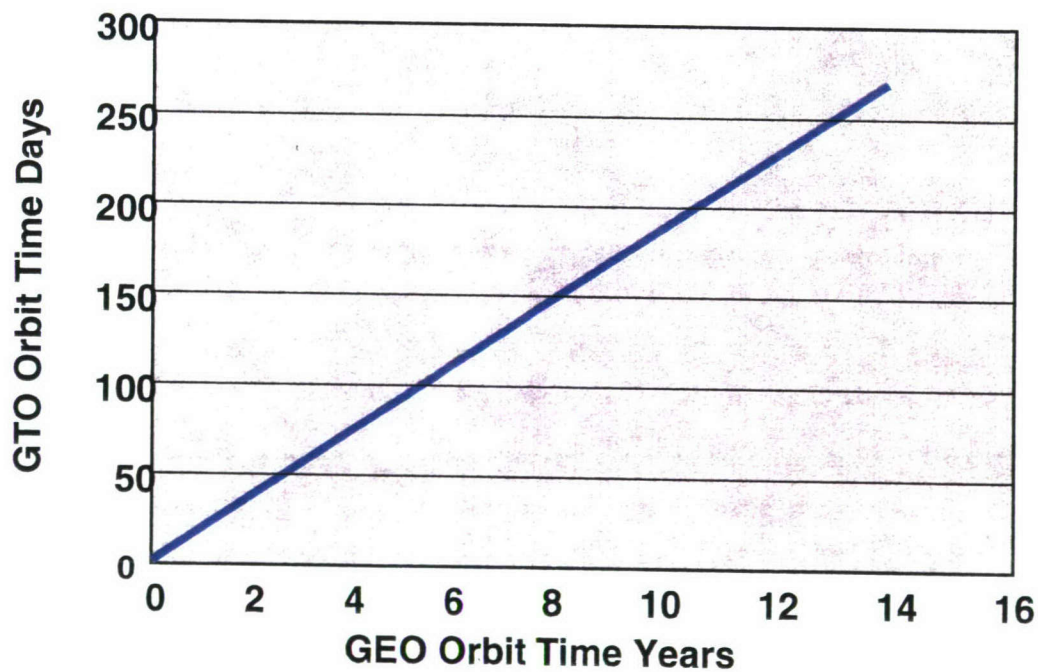
- **GTO flight experiment provides accelerated radiation life test for GEO orbit**
  - 300 days in GTO orbit = 15 years in GEO orbit
  - Data from SPENVIS
  - Free space environment (no shielding)



Cost and Benefits

- PSSC will return valuable on-orbit data on solar cells
- Accurate prediction of solar cells/array EOL performance improves mission assurance
- Flight experiment can reduce the cost of ground testing
- Cost of PSSC Testbed flight is small compared to major program cost and the risk reduction benefit is great

Low Cost Access to Space

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- Recurring Cost for Operational PSSC Testbed Missions $750K to $1000K
  - Spacecraft $250K
  - Launch Services and Integration $250 to $500K
  - 1 year Flight Operations $250K
- Value of Risk Reduction to Operational Programs
  - Priceless

Experiment Concept

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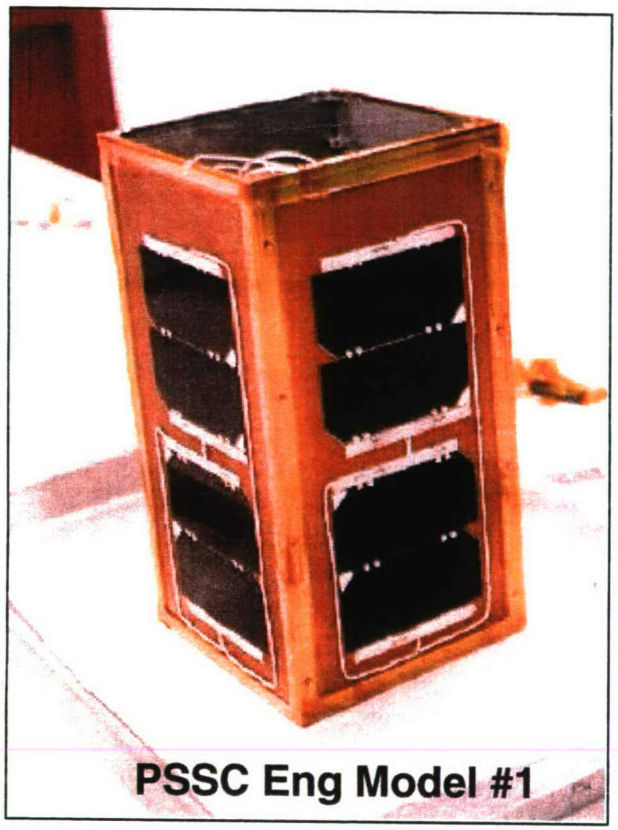

PSSC Eng Model #1

Pico Satellite Solar Cell Testbed

- **Goal**
  - Provide performance data in space environment on advanced solar cells, coverglass, coatings, etc.
- **Method**
  - Free flyer satellite experiment – no recovery needed, data direct to ground station
  - Size: <7 KG; Rectilinear 5x5x10 inches; Based on existing PICOSAT program and designed to use existing SSPL 5510 launcher – low cost, repeatable
  - Measures the degradation of solar cells via current-voltage characteristics, due to space environment
  - Pathfinder mission to fly in LEO orbit to verify operation and focus on atomic oxygen effects
  - Operational mission to fly in GEO transfer orbit to provide accelerated life test (radiation)

Technology & Development

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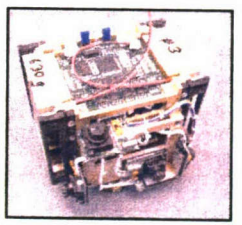
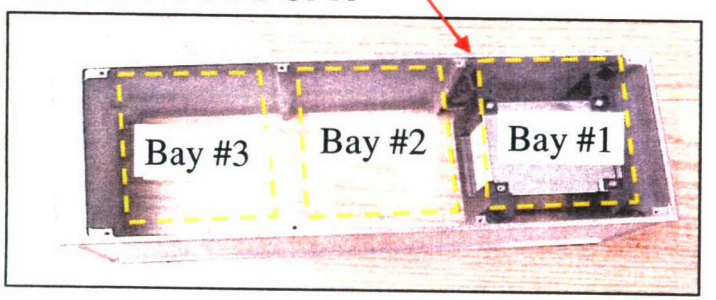
Single Electronics Module



5x5x10 PICOSAT



- **PSSC testbed baseline configuration (one bay of 5x5x10 PICOSAT bus + four external faces):**
  - Flight computer (Complete)
  - Radio (Complete)
  - Battery management (Complete)
  - Solar management (Complete)
  - Radiation detector (In Development)
  - Reaction Wheel Assembly (In Development)
  - Sun Sensor (In Development
- **Hardware TRL:**
  - Current Technology Readiness level is TRL-4
  - Technology Readiness Level After Flight TRL-6
  - Flight Ready Spring 2008

Solar Cell Technology

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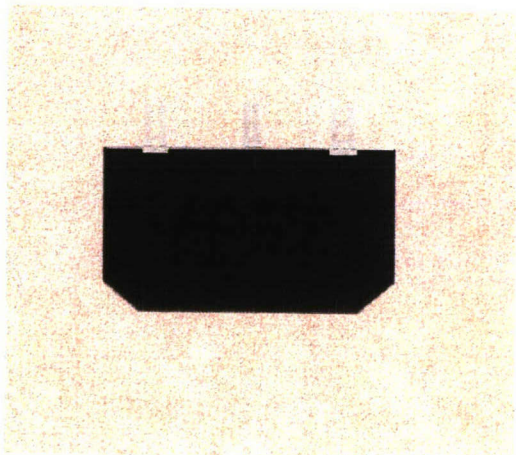
Spectrolab XTJ Solar Cell

- Next generation triple junction solar cell
- >30% efficiency at max power BOL (AM0,135.3, 28°C) demonstrated
- 27% EOL (5e14 1-MeV e-, NP_{mp} = 0.89) predicted based on UTJ performance
- Area of 26.62 cm^2
- Designed to provide an 8% improvement in solar panel power over UTJ
- Built upon UTJ production experience:
  - NVmp, NJmp, & NPmp of 0.91, 0.98, & 0.89, respectively. (5e14, 1-MeV e-)
- Modifications made to epitaxial design – all other materials identical to UTJ
- Latest interconnect and protection diode
  - assembly features as qualified on UTJ



Solar Cell Technology

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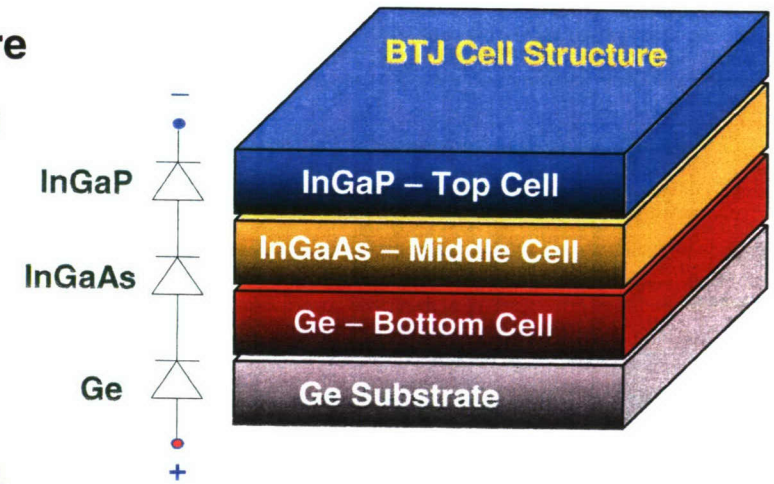
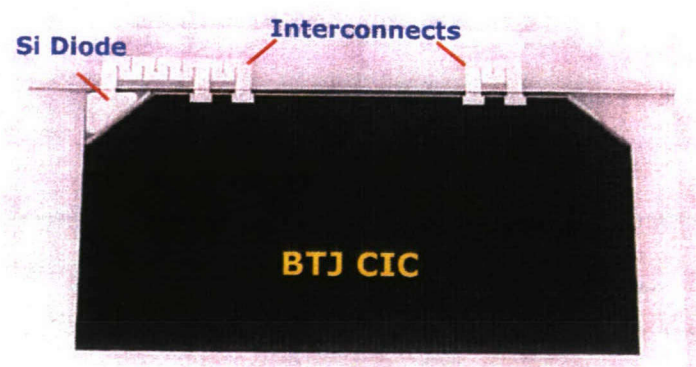
- **Emcore BTJ Solar Cell – 28.5% Minimum Average Efficiency**
  - **Lattice-Matched InGaP/InGaAs/Ge Structure**
  - **Highest Efficiency Solar Cell in Production**

Typical AM0 Electrical Performance					
Voc (mV)	Jsc (mA/cm^2)	Vmp (mV)	Imp (mA/cm^2)	FF (%)	Efficiency (%)
2,702	17.0	2,360	16.4	84.0	28.5



- **Flight Cells Produced w/ Efficiencies >30%**
- **Radiation Tolerance Data**

Fluence (e/cm^2)	Remaining Factors - After 1-MeV Electron Irradiation				
	Voc	Isc	Vmp	Imp	Pmp
1E+14	0.95	0.99	0.96	0.99	0.95
5E+14	0.91	0.97	0.92	0.96	0.89
1E+15	0.89	0.95	0.91	0.93	0.84



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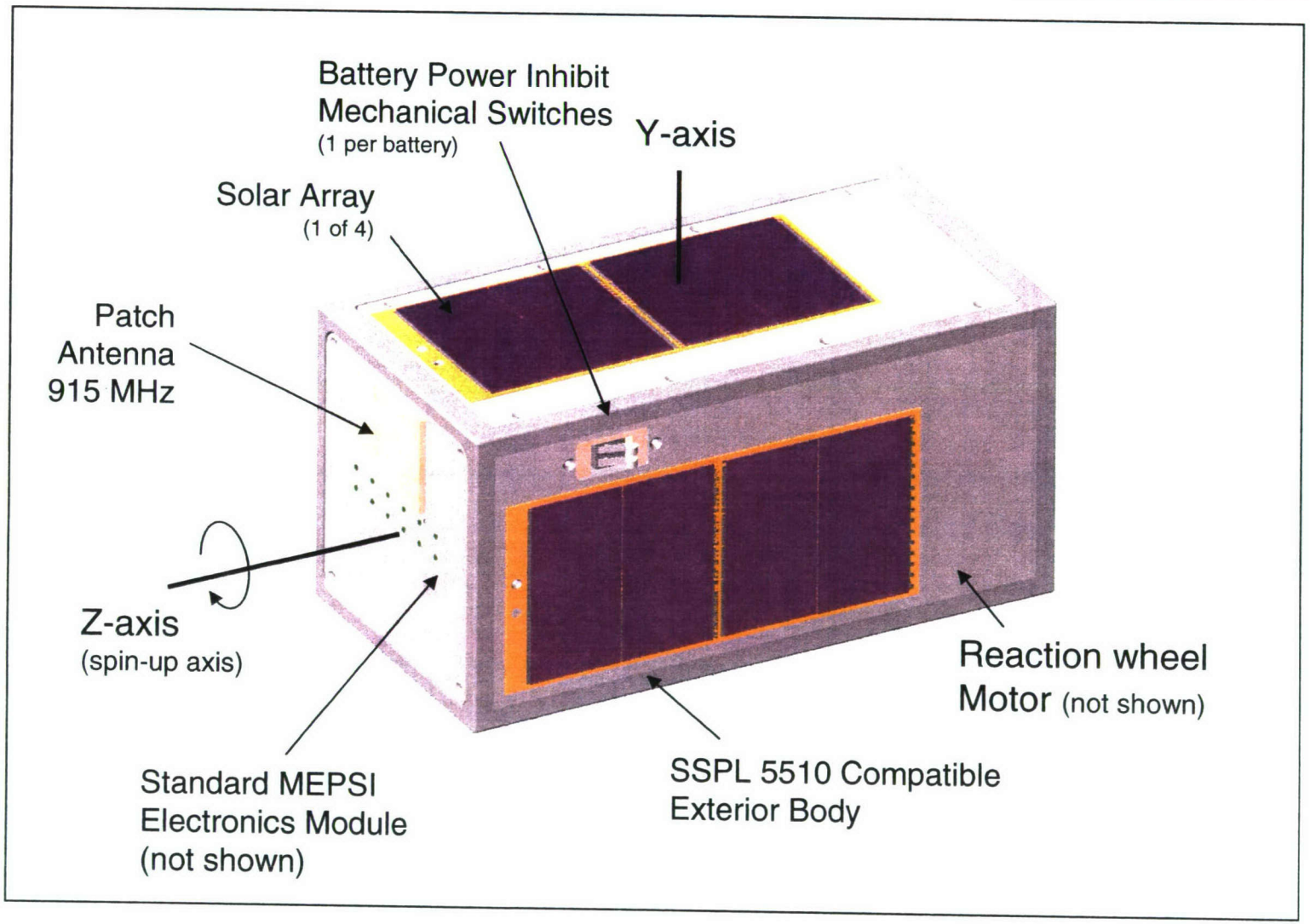
PSSC Spacecraft Design

PSSC Testbed Satellite Overview



PSSC Experiment Spacecraft Components

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- Spacecraft Body
  - 5 inches x 5 inches x 10inches
  - Wall Thickness 0.3 inches
- Power Processing Electronics
  - Battery Boards
  - Solar Array Boards
- Batteries (4)
  - Moli-Energy Cell 18650 Li Ion Cells
- Standard Pico Satellite Processor Board
- 915 MHz Radio
- Reaction Wheel
  - To Spin Stabilize Spacecraft
- Sun Sensor

Photographs of PSSC Testbed Experiment components

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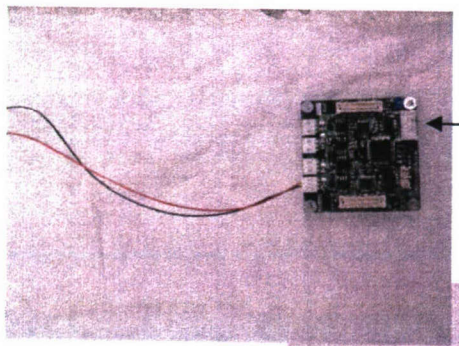
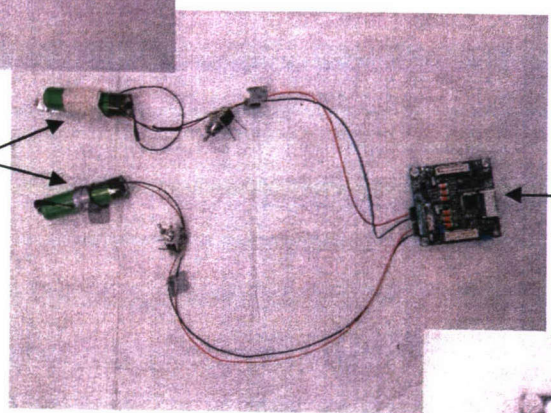
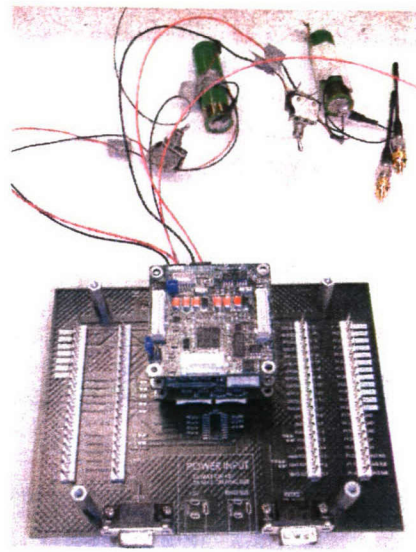


Solar Board

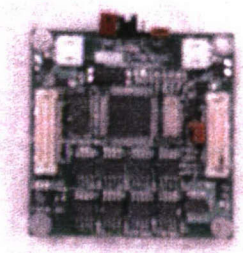


Batteries

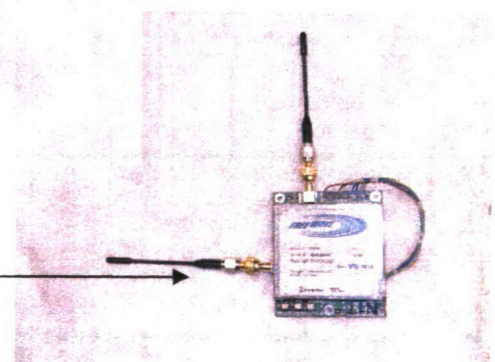
Battery Board



PSSC Boards on Test Fixture

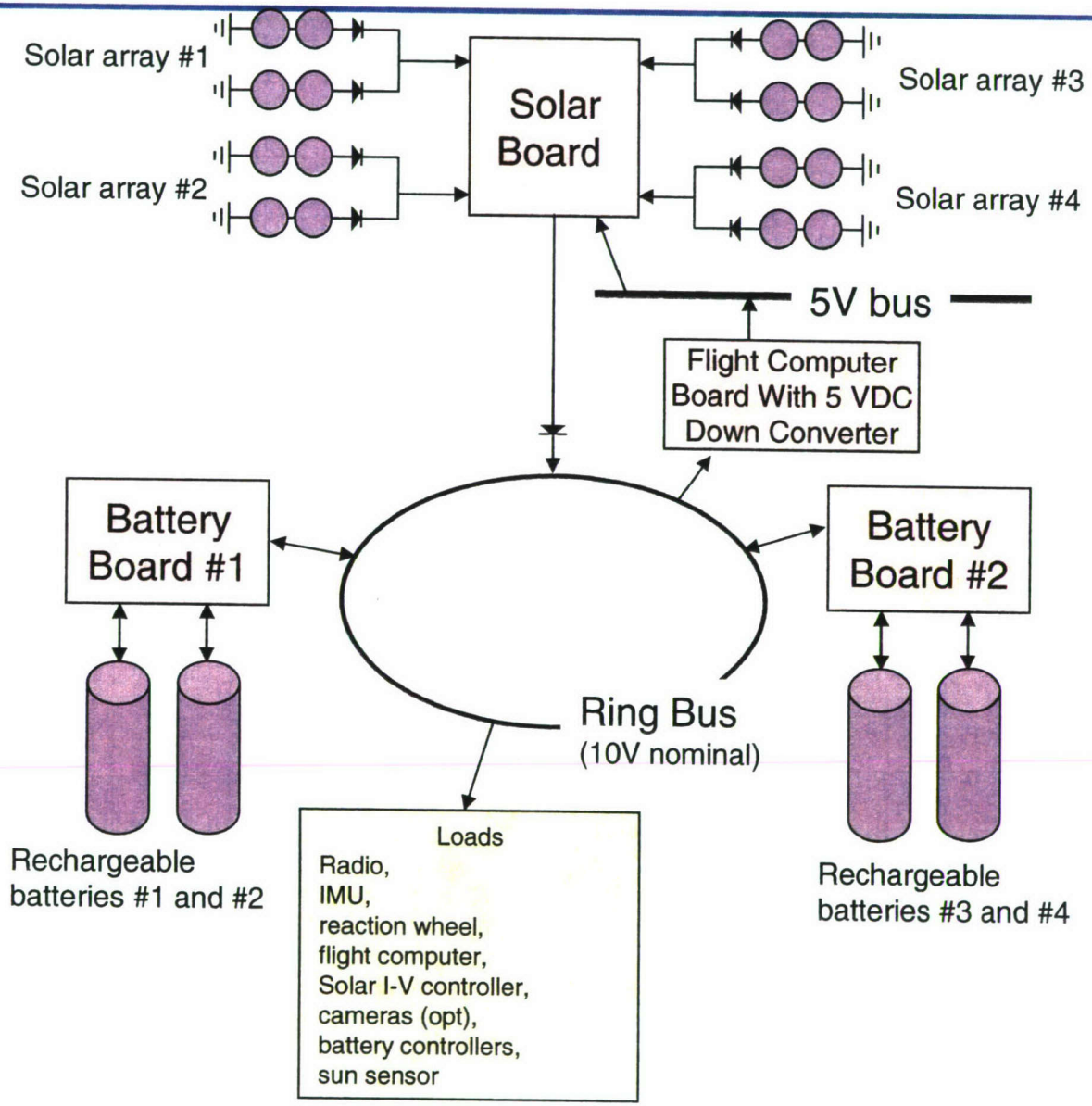


Processor Board



915 MHz Radio

PSSC Testbed Power System Diagram



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Qualification Test Plan

Qualification Test Plan

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- Predicted Temperatures for the PSSC Testbed are -4°C to +37°C
- Aerospace Corporation Technical Report TR-2004(8583)-1 (Replaces Mil STD 1540)
  - Qualification Temperature Requirement
    - Specifies default Temperature Range of -24°C and +61°C when Predicted Range is between -13°C and +50°C
    - PSSC Qualification Temperature Range shall be -34°C to +71°C
  - Acoustic Noise, Random Vibration, Sinusoidal Vibration & Shock Qualification Levels
    - Predicted +6dB

PSSC Testbed Hot Case Temperature Predictions

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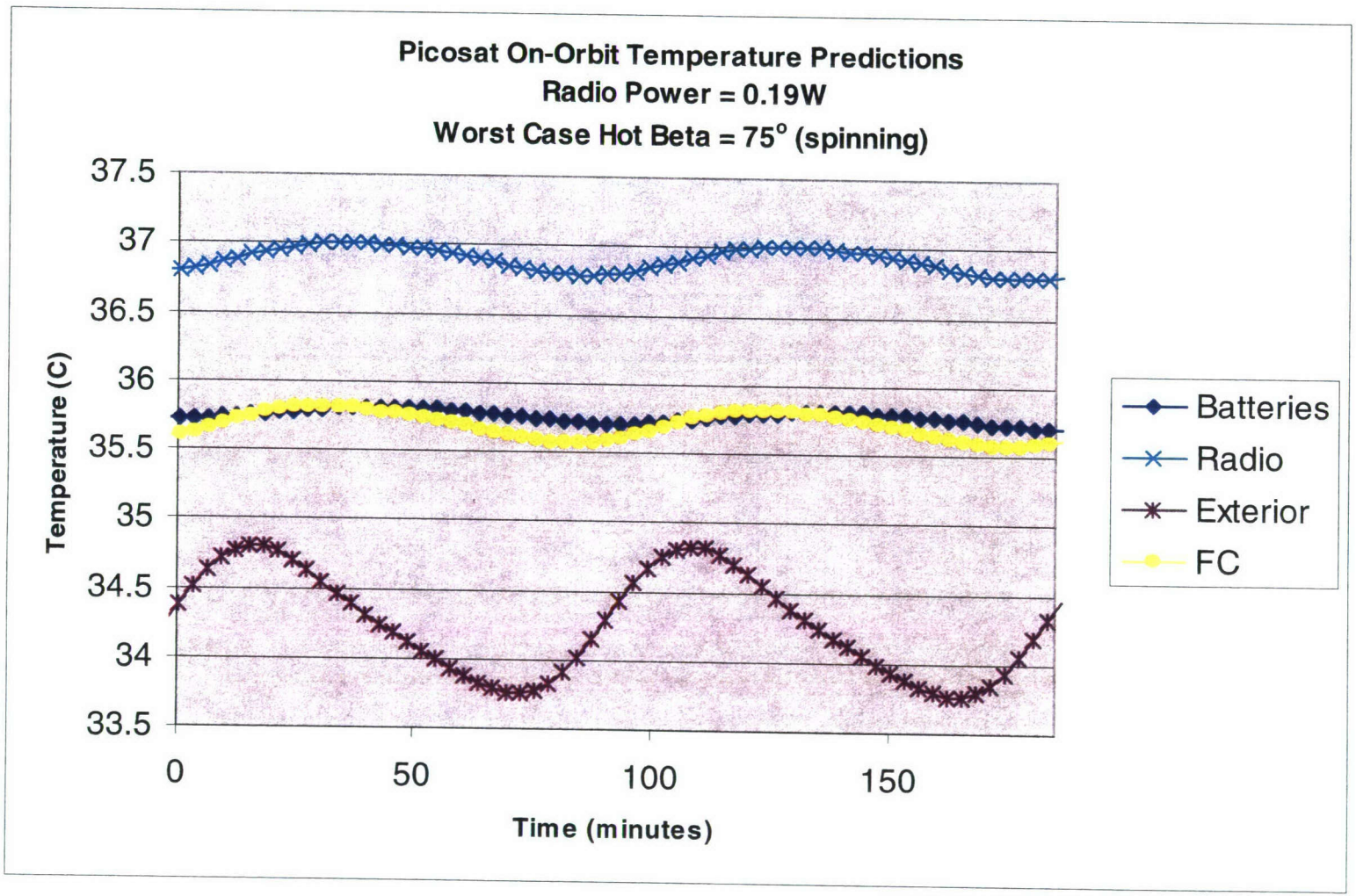
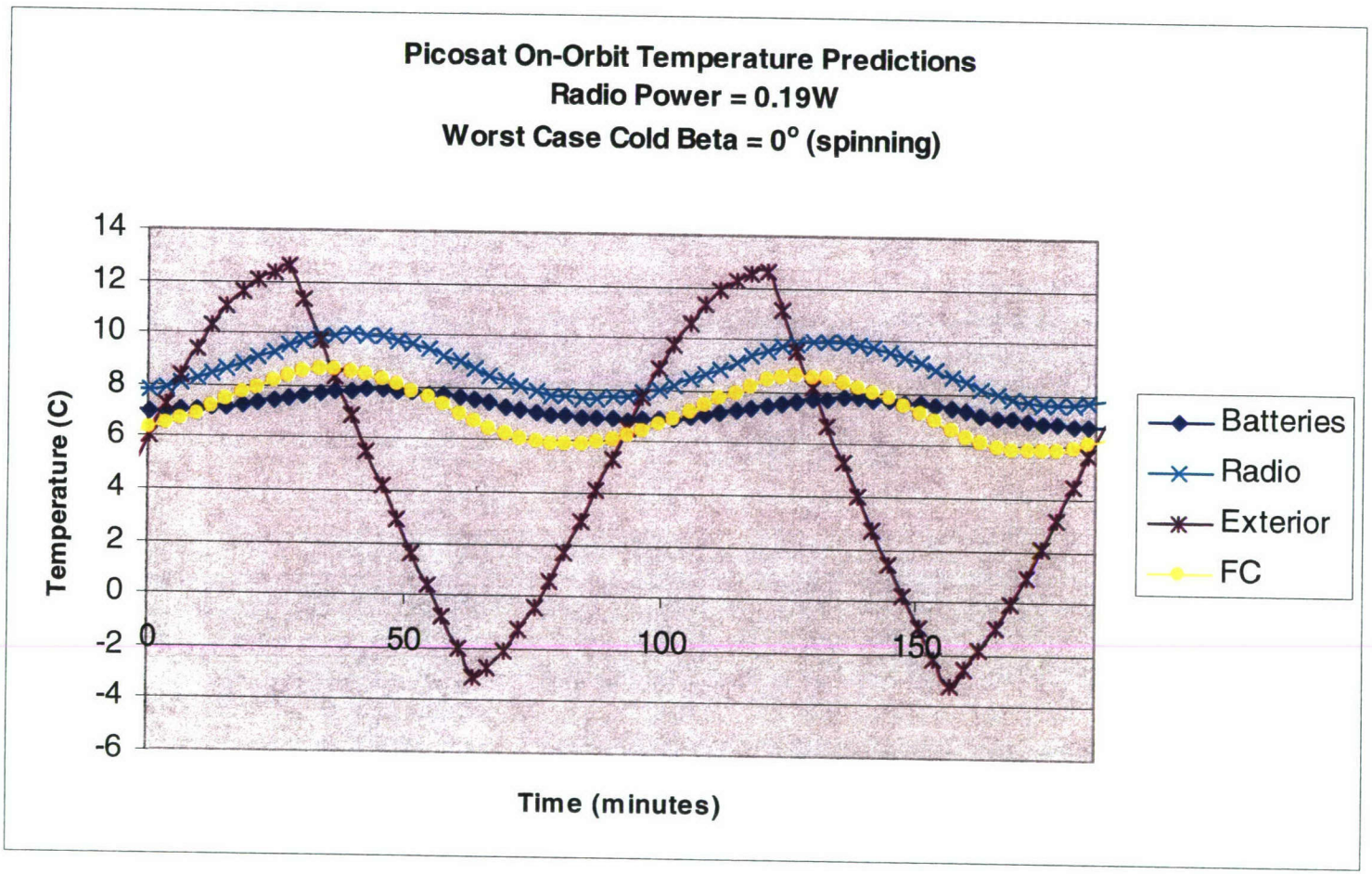
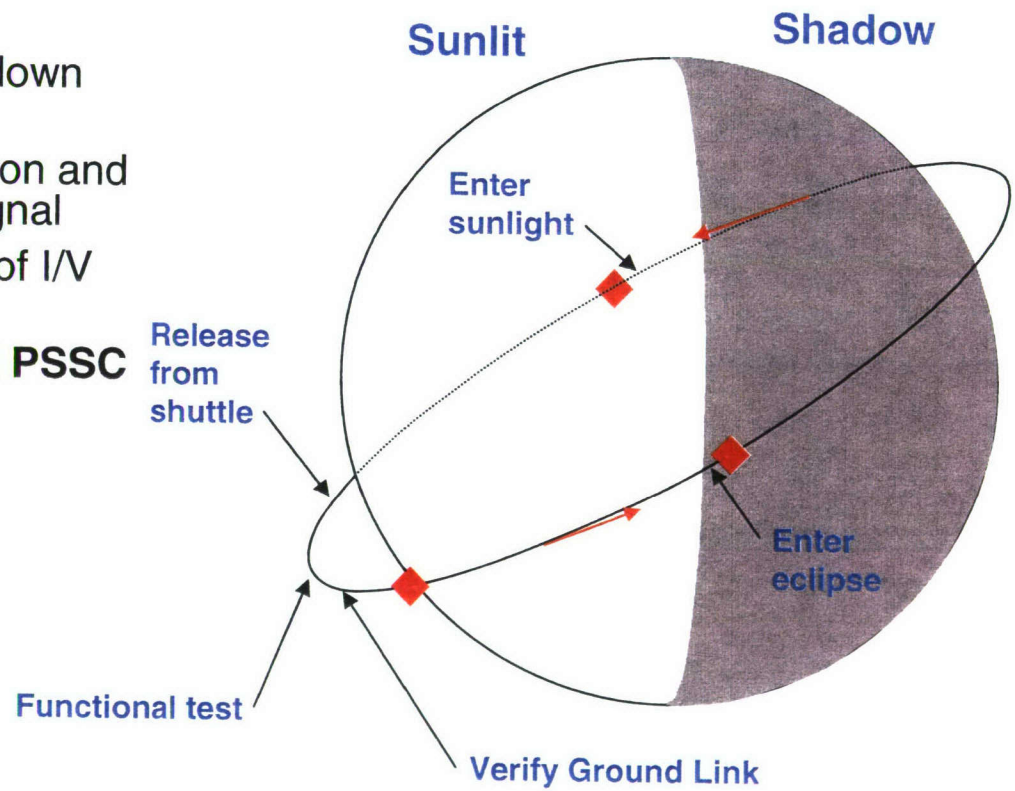


PSSC Testbed Cold Case Temperature Predictions



PSSC Testbed Mission Events

- **PSSC testbed ejected 1st orbit begins**
  - Reaction Wheel Spun up prior to ejection from SSPL 5510
  - Ejection from SSPL 5510 Perpendicular to Earth-Sun Orbit Plane
  - After Ejection Reaction Wheel Spins down imparting spin to PSSC Testbed
  - After TBD delay PSSC Testbed turns on and begins listening for Ground Station signal
  - PSSC Begins regular measurements of I/V data
- **Communications between ground and PSSC testbed begin**
  - Data Downlinked and Commands Uplinked
- **Nth orbit begins**
  - PSSC testbed performs I/V test per program schedule
  - Downlink I/V data at next opportunity
- **Final orbit**
  - Reentry has occurred *or*
  - Spacecraft failure



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Expected Flight Data

Flight Data

- Flight data will be recorded, and downloaded to ground station with PSSC on-board electronic
  - Temperature measurements
    - Solar array, battery, and electronics
    - Temperature will be measured with thermistors
  - Sun angles
    - Measured with camera/linear CCD sun sensor
  - Spacecraft spin rate
    - Spin rate will be determined from the solar array power output
  - Power system health status
    - Solar array, battery, and bus voltage and current
  - Solar cells I-V curves

On-Board I-V Measurement

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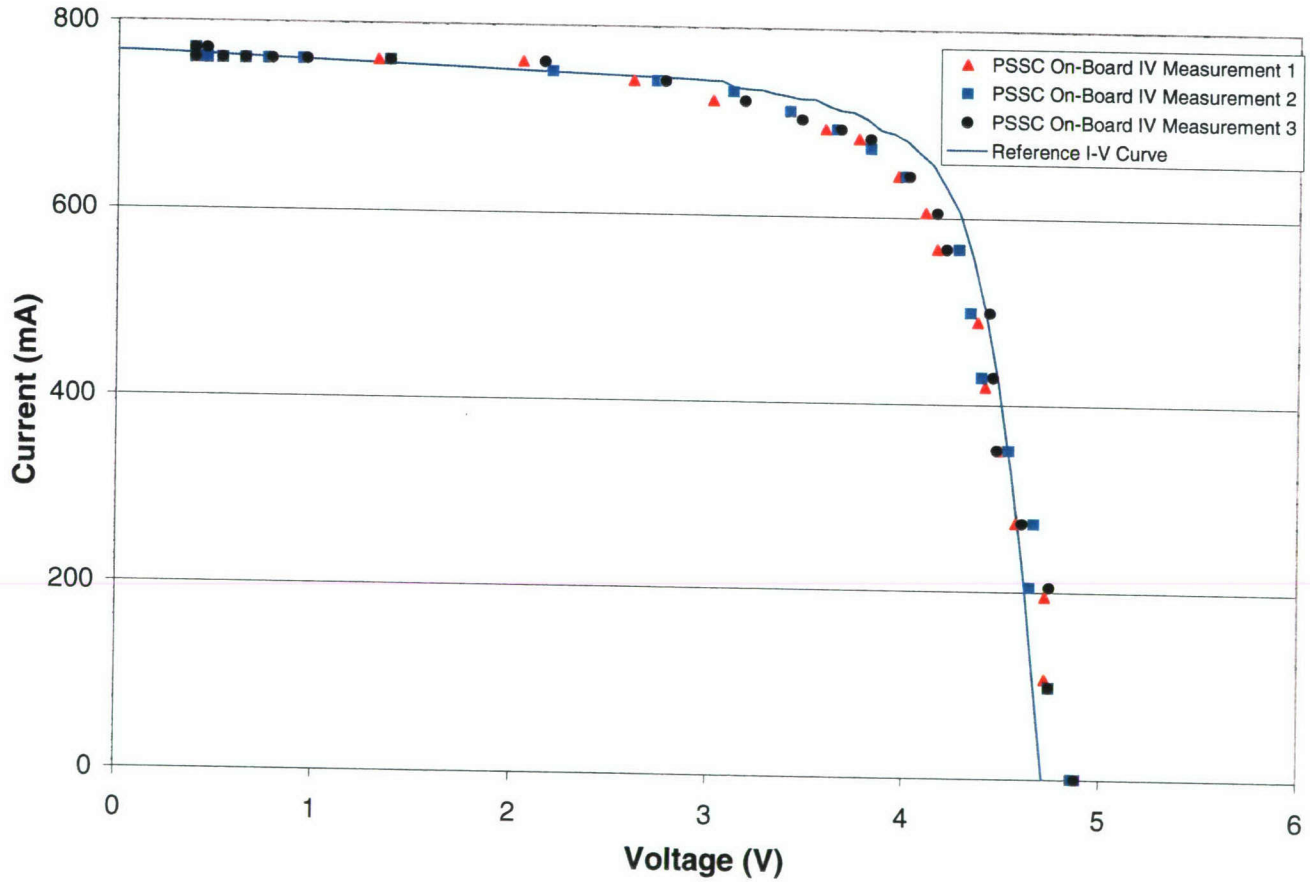
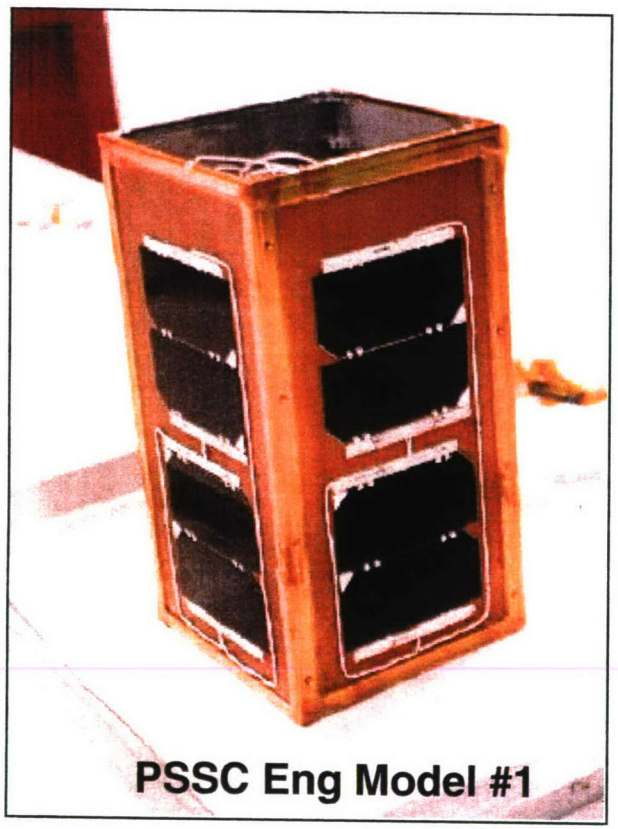
- Ground testing of PSSC on-board I-V measurement showed good agreement with reference I-V curve



Long Term Goals

- Develop capability for solar cell orbital test capability that is responsive to new technology introduction cycle
- Provide data to program office, industry, and manufacturers in a timely manner to reduce risk in applying new solar cell technology
- Provide accelerated radiation data combined with all other space environment factors (fly in GEO transfer orbit)
- Low cost platform for testing new technologies prior to deployment

Summary



PSSC Eng Model #1

- Provide Air Force with affordable vehicle for obtaining Space Environment Degradation Data for Advanced Solar Cells
- Provide Air Force with Pico Satellite Bus Capable of Hosting other Experiment Payloads

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Laboratory Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual organizations:

Electronics and Photonics Laboratory: Microelectronics, VLSI reliability, failure analysis, solid-state device physics, compound semiconductors, radiation effects, infrared and CCD detector devices, data storage and display technologies; lasers and electro-optics, solid-state laser design, micro-optics, optical communications, and fiber-optic sensors; atomic frequency standards, applied laser spectroscopy, laser chemistry, atmospheric propagation and beam control, LIDAR/LADAR remote sensing; solar cell and array testing and evaluation, battery electrochemistry, battery testing and evaluation.

Space Materials Laboratory: Evaluation and characterizations of new materials and processing techniques: metals, alloys, ceramics, polymers, thin films, and composites; development of advanced deposition processes; nondestructive evaluation, component failure analysis and reliability; structural mechanics, fracture mechanics, and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena. Microelectromechanical systems (MEMS) for space applications; laser micromachining; laser-surface physical and chemical interactions; micropropulsion; micro- and nanosatellite mission analysis; intelligent microinstruments for monitoring space and launch system environments.

Space Science Applications Laboratory: Magnetospheric, auroral and cosmic-ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; infrared surveillance, imaging and remote sensing; multispectral and hyperspectral sensor development; data analysis and algorithm development; applications of multispectral and hyperspectral imagery to defense, civil space, commercial, and environmental missions; effects of solar activity, magnetic storms and nuclear explosions on the Earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation, design, fabrication and test; environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions, and radiative signatures of missile plumes.